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ADVANCED INJECTOR CONCEPTS INVESTIGATION

CONTRACT NAS 8-21052

FINAL SUMMARY REPORT TO

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Report 21052-3FS

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AEROJET LIQUID ROCKET COMPANY

A DIVISION OF AEROJET-GENERAL

SACRAMENTO, CALIFORNIA

Final Report 21052-3FS

ADVANCED INJECTOR CONCEPTS INVESTIGATION

Prepared Under

Contract NAS 8-21052
Plus Modifications 7 through 10

for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama

FOREWORD

This report summarizes the work accomplished under Contract NAS 8-21052, "Advanced Injector Concepts Investigation". A more detailed account of the work may be found in Report 21052-3F, the final report. The program technical effort extended over a 18-month period and was completed on 31 December 1970.

The work was conducted under the cognizance of the Engine Components Department, Aerojet Liquid Rocket Company, Sacramento, California. Key Aerojet program personnel included Dr. N. E. Van Huff, program manager; Mr. J. F. Addoms, project manager; Mr. R. L. Boyce, project engineer; and Dr. R. J. LaBotz, technical specialist. Overall program direction was provided by the NASA technical manager, Mr. R. J. Richmond.

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FIGURE LIST

I. INTRODUCTION

The purpose of this program was to continue exploration of a throttling injector concept that is applicable to an advanced cryogenic engine. This program is Phase III of Contract NAS 8-21052, initiated by Marshall Space Flight Center.

Phase I of the program included evaluation of injectors suitable for staged combustion systems incorporating primary and secondary injectors as well as an annular-shaped combustor in which hydrogen is preheated in a regeneratively cooled jacket. These engine systems had in common the requirement for successful operation while throttling over a wide thrust range. The concept utilized in each of the injector designs is designated HIPERTHIN*. The four subscale HIPERTHIN injector system investigated during Phase I were: (1) an annular heat exchanger/injector combustor segment designed for liquid oxygen and gaseous hydrogen--this injector segment simulates the conditions anticipated in a hydrogen regeneratively cooled annular combustor; (2) a primary combustor injector which produces hydrogen-rich hot gas required in a staged-combustion system; (3) a secondary combustor injector which operates with liquid oxygen and hot hydrogen-rich primary combustor gas; and (4) an alternative secondary combustor injector design for use in staged-combustion cycles that employ both fuel- and oxidizer-rich primary combustors. Phase I was reported in Report 21052-1F, dated 31 July 1968.

During Phase II, the areas of performance, injector $\Delta P/P_c$ behavior, face cooling, throttling range, and combustion stability characteristics of the HIPERTHIN annular heat exchanger/injector combustor segment were examined in more detail. Additionally, certain fabrication problems met during Phase I were resolved. The annular heat exchanger/injector segment development was continued, as this injector appeared to be the best for use in conjunction with an advanced cryogenic rocket engine. This segment was designed for liquid

* A concept developed and owned by Aerojet-General Corporation on which AGC holds Patent No. 3,413,704 and other patents pending.

I, Introduction (cont.)

oxygen and gaseous hydrogen, simulating the conditions anticipated in a hydrogen regeneratively cooled annular combustor. Phase I was reported in Report 21052-2F, dated January 1970.

II. SUMMARY

Phase III of Contract NAS 8-21052 was initiated 1 July 1969 and was divided into two tasks:

Task I was an analytical investigation of the feasibility of tapping turbine drive gases from the chamber and passing them through the HIPERTHIN injector. This effort consisted of analysis and preliminary design only; no hardware was fabricated for experimentation.

In operation, gases tapped from the combustion chamber are passed back through the injector counter to the flow of incoming propellants. The problem was to determine if--by proper sizing of the hot gas channels and the propellant injection channels--an optimum heat transfer area could be provided to enable the hot gases to yield sufficient energy to gasify the incoming propellants, and yet retain sufficient energy to drive the turbopump after leaving the injector/heat exchanger. Figure 1 shows the concept schematically.

It was concluded that the hot gas tapoff cycle injector concept is feasible and can operate successfully over the full throttling range specified (33:1), using nickel as the injector material. Certain practical considerations such as the extremely short length of the injector (0.3 in.) may tend to diminish the desirability of employing this concept. Copper was also briefly considered for the tapoff injector material and, from an analytical standpoint, is superior to nickel for this application as shown by Figure 2.

II, Summary (cont.)

Task II was devoted to further exploration of the annular segment injector, Figure 3, primarily to gain additional data regarding combustion stability, injector face cooling, and steady-state performance at chamber pressures up to 2500 psia. The longer firing durations required to ensure steady-state data and the higher chamber pressures required the use of nickel injector platelet material for improved injector face cooling and water cooling of the chamber.

The objectives of the annular segment injector work for Phase III were to demonstrate that the HIPERTHIN is adequate for mechanical strength operation at high chamber pressures, to determine the maximum pressure (up to 2500 psia) at which the thruster could be operated without burning the injector face, and to demonstrate that the desired throttling range could be realized at short L' with high performance.

Most of these objectives were met. The mechanical strength of HIPERTHIN was demonstrated by ten tests of one injector at chamber pressures varying from 100 to 1300 psia. The same injector was also subjected to numerous cold flow cycles and is still structurally sound. No face burning was evident up to the highest chamber pressure level tested (1300 psia) and combustion was stable. Performance ranged from an energy release efficiency of 98% at the 100 psia P_c level to 94% at the higher chamber pressure.

The chamber used for test firings was a copper-lined water-cooled thrust chamber with a two-dimensional rectangular converging section and throat. The basic chamber length was 2.5 in. (7.3 in. L*), but attachments for nozzles were provided so that nozzle extensions could be added for operation. The test hardware is shown in Figures 4 and 5.

Use of the Nickel 200 platelet material, required because of face overheating experienced with the stainless steel injectors of Phase II, presented

II, Summary (cont.)

some fabrication problems. Many of the platelets were inadequately plated with the electroless nickel braze material. As a result, both platelet stacks leaked at the edges, but both were successfully repaired and one injector was later tested at 1300 psia with no leakage problems. A procedure has been devised to preclude recurrence of this problem. Two nickel injectors were fabricated for Phase III, although only one was required to conduct the test series.

III. CONCLUSIONS

A. TAPOFF CYCLE

1. The basic tapoff cycle is analytically sizeable up to chamber pressures of 2500 psia with nickel platelet injectors.

2. Above 2500 psia, the permissible tolerances on operating conditions are too small for a practical tapoff cycle with nickel injectors.

3. Copper should be considered as a substitute for nickel in the tapoff system at pressures of 2500 psia and above.

B. ANNULAR INJECTOR DESIGN

1. The integral heat exchanger/injector design concept for extended throttling was demonstrated to be feasible over a throttling range of 13:1 (chamber pressures of 100 to 1300 psia).

2. The design modifications to the heat exchanger section were effective in vaporizing the oxygen and providing uniform, nonpulsing injection.

III, B, Annular Injector Design (cont.)

3. The basic analytical tools employed in injector hydraulic design are suitable for conventional platelet passages. Some modification to the model is required to account for the hydraulic affect of the turbulators added to the LO_2 heat exchanger section.

4. The injector is structurally adequate at chamber pressures of at least 1300 psia and differential manifold pressures of at least 1600 psi.

5. The nickel platelet material was effective in extending the face cooling capacity to at least 1300 psia chamber pressure.

6. The 2.50-in. chamber length may be too short for maximum efficiency.

C. FABRICATION

1. Full-scale injectors can be fabricated from Nickel 200 platelets as readily as from stainless steel platelets.

2. The technique of copper flashing the nickel platelets prior to depositing the electroless nickel braze alloy is an effective quality control technique for assuring complete braze alloy coverage.

D. OPERATING CHARACTERISTICS

1. A 2.50-in. L' chamber is adequate for HIPERTHIN injectors to provide combustion efficiency in excess of 97% at chamber pressures in the 100 to 500 psia range using O_2/H_2 propellants at O/F of between 5.73 and 6.45.

2. The combustion efficiency measured was lower at higher chamber pressures and/or higher mixture ratios.

III, D, Operating Characteristics (cont.)

3. The observed reduction in ERE with increasing P_c and decreasing O/F is due mainly to increasing P_c.

4. The short 2.50-in. length chamber may denote performance characteristics such as reaction isolation zones, which tend to inhibit mixing, that would normally not be seen in longer length chambers.

5. Results cast doubt that a combustion system can be made to throttle over a wide range while maintaining a <u>constant</u>, high ERE.

IV. RECOMMENDATIONS

A. Determine quantitatively the efficiency and heat transfer capabilities of the injector heat exchanger section.

B. Determine the minimum injector ΔP and/or $\Delta P/P_c$ required for stable operation.

C. Expand the platelet technology to include copper platelets for application to the tapoff cycle.

D. Modify the heat exchanger computer model to improved hydraulic predictions.

E. Determine the parameters causing the observed combustion efficiency reduction at higher chamber pressures.

F. Determine the interrelationship between operating mixture ratio and operating chamber pressure on combustion efficiency.

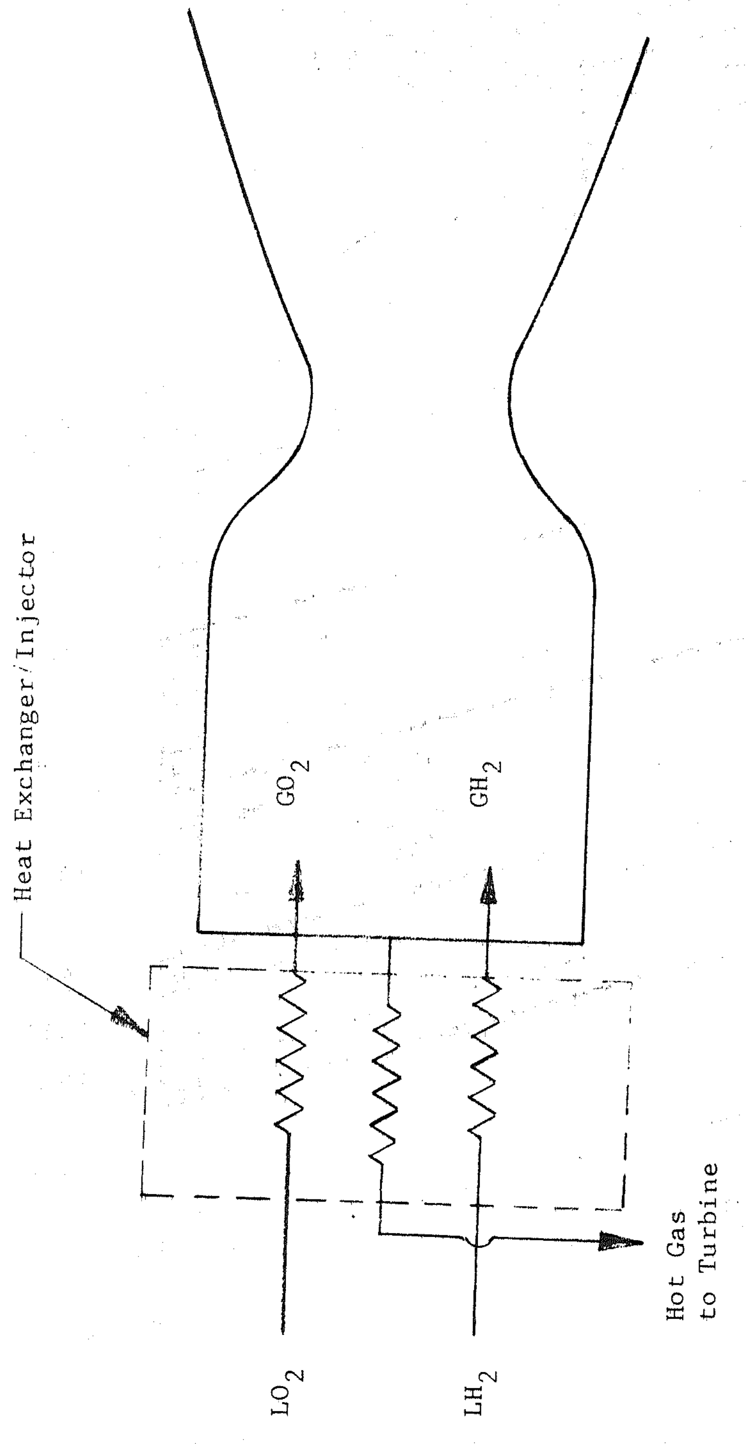

Figure 1. Simple Tapoff Schematic

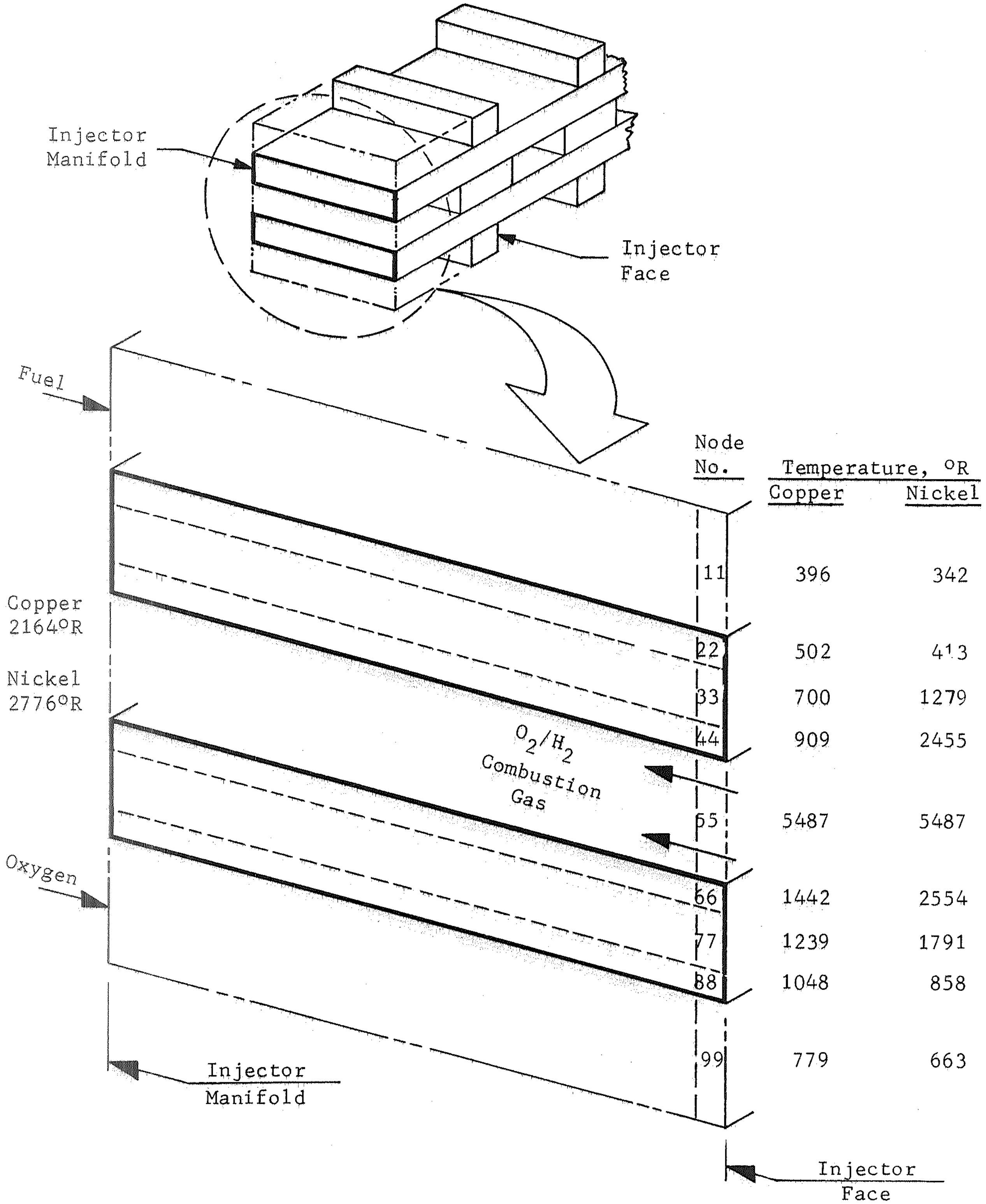

Figure 2. Temperature Comparison Between Copper and Nickel at Injector Face Nodes and Hot Gas Outlet

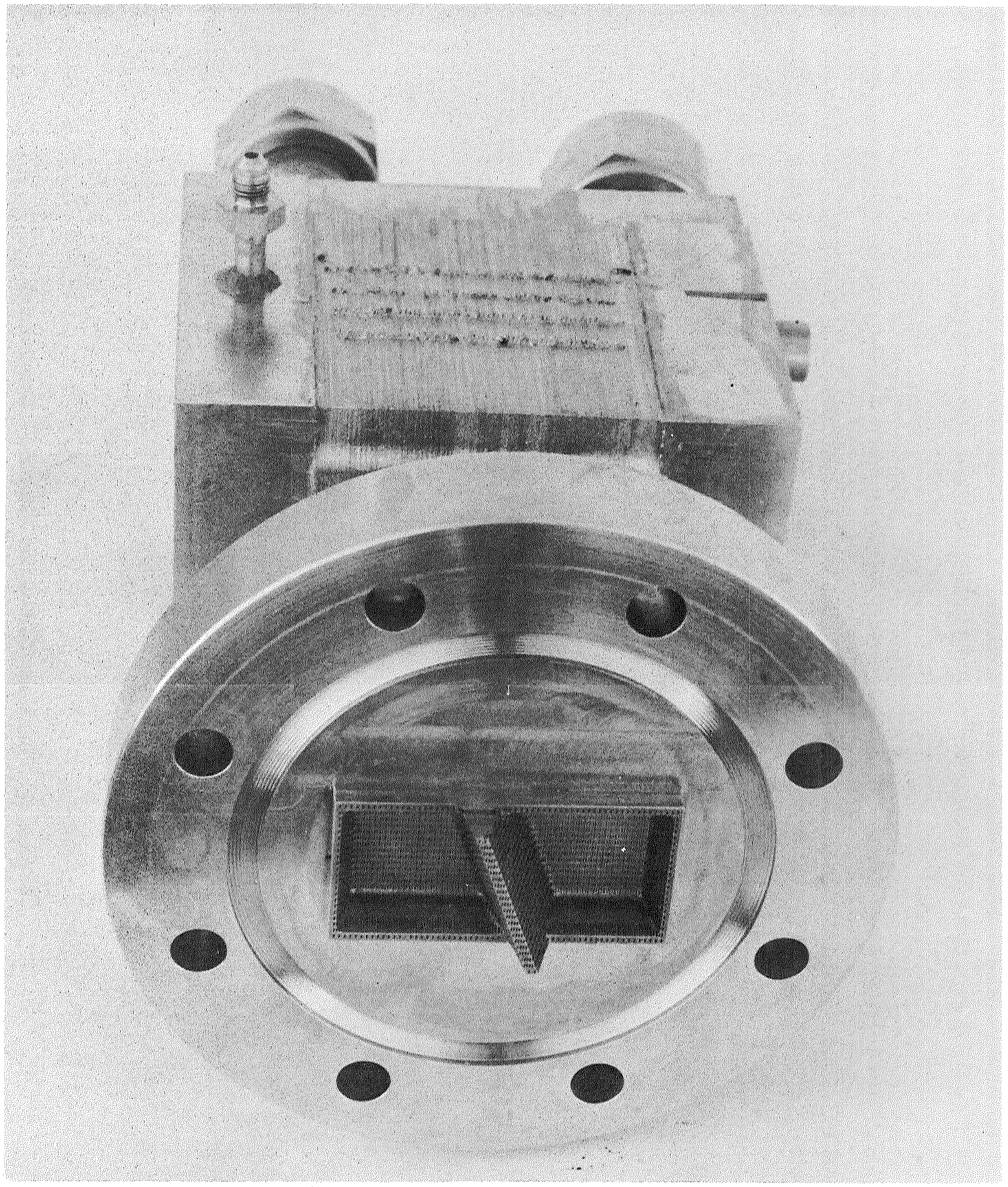

Figure 3. Annular Segment Injector

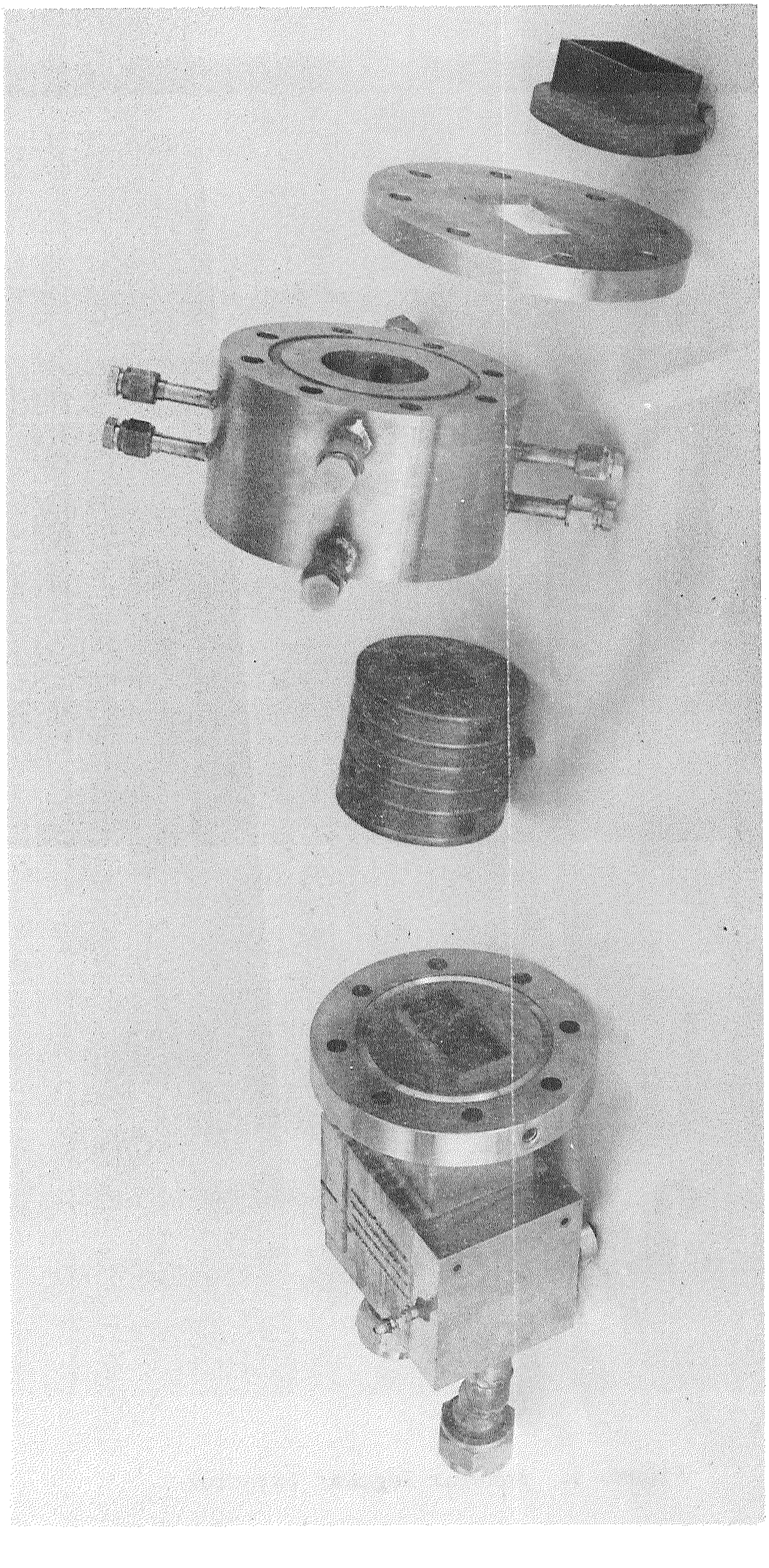

Figure 4. Annular Combustor Assembly Components

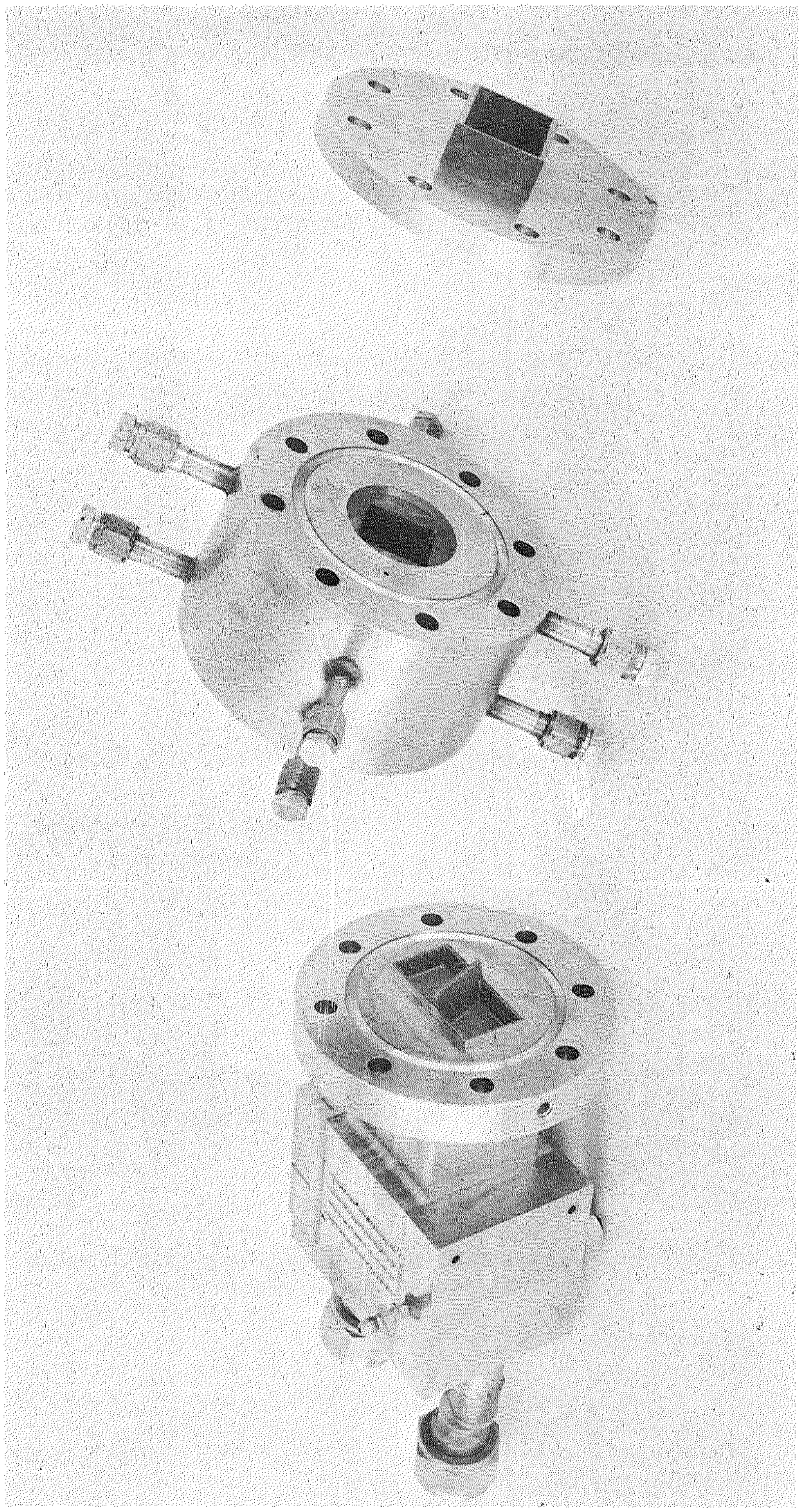

Figure 5. Annular Combustor Assembly